

**Collaborative Study for Analysis of high Resolution  
Infrared Atmospheric Spectra Between NASA Langley  
Research Center and the University of Denver**

**NASA Langley Research Center**

**Contract NCCI-48**

**Final Report  
Summary of Research**

**Submitted by**

**A. Goldman**

**Department of Physics**

**University of Denver**

**Denver, CO 80208**

**Nov. 15, 1999**

## Summary of Research

The Langley-D.U. collaboration on the analysis of high resolution infrared atmospheric spectra covered a number of important studies of trace gases identification and quantification from field spectra, and spectral line parameters analysis.

The collaborative work included:

- \* Quantification and monitoring of trace gases from ground-based spectra available from various locations and seasons and from balloon flights.
- \* Studies toward identification and quantification of isotopic species, mostly Oxygen and Sulfur isotopes.
- \* Search for new species on the available spectra.
- \* Update of spectroscopic line parameters, by combining laboratory and atmospheric spectra with theoretical spectroscopy methods.
- \* Study of trends of atmosphere trace constituents.
- \* Algorithms developments, retrievals intercomparisons and automatization of the analysis of NDSC spectra, for both column amounts and vertical profiles.

Listed in the following are joint publications completed over the years under this project.

Rinsland, C.P., M.A.H. Smith, P.L. Rinsland, A. Goldman, J.W. Brault, and G.M. Stokes, "Ground-Based Infrared Spectroscopic Measurements of Atmospheric Hydrogen Cyanide," *J. Geophys. Res.*, 87, 11,119-11,125, 1982.

Rinsland, C.P., M.A.H. Smith, R.K. Seals Jr., A. Goldman, F.J. Murcray, D.G. Murcray, J.C. Larsen, and P.L. Rarig, "Stratospheric Measurements Collision-Induced Absorption by Molecular Oxygen," *J. Geophys. Res.*, 87, 3119-3122, 1982.

Rinsland, C.P., A. Goldman, F.J. Murcray, D.G. Murcray, M.A.H. Smith, R.K. Seals, Jr., J.C. Larsen, and P.L. Rinsland, "Stratospheric N<sub>2</sub>O Mixing Ratio Profile from High Resolution Balloon-Borne Solar Absorption Spectra and Laboratory Spectra near 1880 cm<sup>-1</sup>," *Appl. Opt.*, 21, 4351-4355, 1982.

Rinsland, C.P., A. Goldman, F.J. Murcray, D.G. Murcray, M.A.H. Smith, R.K. Seals, Jr., J.C. Larsen, and P.L. Rinsland, "Stratospheric Temperature Profile from Balloon-Borne Measurements of the 10.4  $\mu\text{m}$  Band of  $\text{CO}_2$ ," *J. Quant. Spectrosc. Radiat. Transfer.*, 30, 327-334, 1983.

Smith, M.A.H., G.A. Harvey, G.L. Pellett, A. Goldman, and D.J. Richardson, "Measurements of the  $\text{HCNv}_3$  Band Broadened by  $\text{N}_2$ ," *J. Mol. Spectrosc.* 105, 105-112, 1984.

Rinsland, C.P., A. Goldman, V.M. Devi, B. Fridovich, D.G.S. Snyder, G.D. Jones, F.J. Murcray, D.G. Murcray, M.A.H. Smith, R.K. Seals, Jr., M.T. Coffey, and W.G. Mankin, "Simultaneous Stratospheric Measurements of  $\text{H}_2\text{O}$ ,  $\text{HDO}$ , and  $\text{CH}_4$  from Balloon-Borne and Aircraft Infrared Solar Absorption Spectra and Tunable Diode Laser Laboratory Spectra of  $\text{HDO}$ ," *J. Geophys. Res.* 89, 7259-7266, 1984.

Goldman, A., J.R. Gillis, C.P. Rinsland, F.J. Murcray, and D.G. Murcray, "Stratospheric  $\text{HNO}_3$  Quantification from Line-by Line, Non-Linear Least Squares Analysis of High Resolution Balloon-Borne Solar Absorption Spectra in the  $870 \text{ cm}^{-1}$  Region," *Appl. Opt.* 23, 3252-3255, 1984.

Rinsland, C.P., R.E. Boughner, J.C. Larsen, A. Goldman, F.J. Murcray, and D.G. Murcray, "Stratospheric NO and  $\text{NO}_2$  Profiles at Sunset from Analysis of High-Resolution Balloon-Borne Infrared Solar Absorption Spectra Obtained at  $33^\circ\text{N}$  and Calculations with a Time-Dependent Photochemical Model," NASA Technical Memorandum, August, 1984.

Goldman A., C.P. Rinsland, F.J. Murcray, D.G. Murcray, M.T. Coffey, and W.G. Mankin, "Balloon-Borne and Aircraft Infrared Measurements of Ethane ( $\text{C}_2\text{H}_6$ ) in the Upper Troposphere and Lower Stratosphere," *J. Atmos. Chem.* 2, 211-221, 1984.

Rinsland, C.P., A. Goldman, D.G. Murcray, F.J. Murcray, f.S. Bonomo, V. Malathy Devi, M.A.H. Smith, and P.L. Rinsland, "Tentative Identification of the  $780 \text{ cm}^{-1}$  Band Q Branch of Chlorine Nitrate in High-Resolution Solar Absorption Spectra of the Stratosphere," *J. Geophys. Res.*, 90, 7931-7943, 1985.

Coffey, M.T., W.G. Mankin, A. Goldman, C.P. Rinsland, G.A. Harvey, V. Malathy Devi, and G.M. Stokes, "Infrared Measurements of Atmospheric Ethane ( $\text{C}_2\text{H}_6$ ) from Aircraft and Ground-Based Solar Absorption Spectra in the  $3000 \text{ cm}^{-1}$  Region," *Geophys. Res. Lett.*, 12, 199-202, 1985.

Rinsland, C.P., A. Goldman, and G.M. Stokes, "Identification of Atmospheric  $\text{C}_2\text{H}_2$  Lines in the  $3230-3340 \text{ cm}^{-1}$  Region of High Resolution Solar Absorption Spectra Recorded at the National

Solar Observatory," *Appl. Opt.*, 24, 2044-2046, 1985.

Larsen, J.C., C.P. Rinsland, A. Goldman, D.G. Murcray, and F.J. Murcray, "Upper Limits for Stratospheric  $H_2O_2$  and HOCL from High Resolution Balloon-Borne Infrared Solar Absorption Spectra," *Geophys. Res. Lett.*, 12, 663-666, 1985.

Barbe, A., L.R. Brown, B. Carli, A. Goldman, N. Husson, H. Pickett, A. Roche, L. Rothman, and M.A. Smith, 1985 Atmospheric Ozone Database (IR to Microwave), 1986.

Husson, N., A. Chedin, N.A. Scott, D. Bailly, G. Graner, N. Lacome, A. Levy, C. Rossetti, G. Tarrago, C. Camy-Peyret, J.M. Flaud, A. Bauer, N. Monnanteuil, J.C. Hilico, G. Peirre, M. Loete, J.p. Champion, L.S. Rothman, L.R. Roghman, L.R. Brown, G. Orton, P.... Varanasi, C.P. Rinsland, M.A.H. Smith, and A. Goldman, The GEISA Spectroscopic Line Parameters Data Bank in 1984. *Annales Geophysicae*, 4, A, 2, 185-190, 1986.

Murcray, F.J., F.H. Murcray, C.P. Rinsland, A. Goldman, and D.G. Murcray, "Infrared Measurements of Several Nitrogen Species above the South Pole in December 1980 and November-December 1986," *Geophys. Res. Lett.*, 92, 13,373-13,376, 1987.

Rothman, L.S., R.R. Gamache, A. Goldman, L.R. Brown, R.A. Toth, H.M. Pickett, R.L. Poynter, J.-M. Flaud, C. Camy-Peyret, A. Barbe, N. Husson, C.P. Rinsland, and M.A.H. Smith, "The Hitran Database: 1986 Edition," *Appl. Opt.* 26, 4058-4097, 1987.

Rinsland, C.P., A. Goldman, F.J. Murcray, F.H. Murcray, D.G. Murcray and J.S. Levine, "Infrared Measurements of Increased  $CF_2Cl_2$  (CFC-12) Absorption Above the South Pole," *Appl. Opt.*, 27, 627-630, 1988.

Goldman, A., C.P. Rinsland, F.S. Murcray, F.H. Murcray, and D.G. Murcray, "Measurements of Several Atmospheric Gases Above the South Pole in December 1986 from High Resolution 3-4-Micron Solar Spectra," *J. Geophys. Res.*, 93, 7069-7074, 1988.

Pickett, H.M., E.A. Cohen, L.R. Brown, C.P. Rinsland, M.A.H. Smith, V. Malathy Devi, A. Goldman, A. Barbe, B. Carli, and M. Carlotti, "The Vibrational and Rotational Spectra of Ozone for the (0,1,0) and (0,2,0,) States," *J. Molec. Spectrosc.*, 128, 151-171, 1988.

Rinsland, C.P., A. Goldman, F.J. Murcray, F.H. Murcray, and D.G. Murcray, "Infrared Measurements of Atmospheric Gases Above Mauna Loa, Hawaii, in February 1987," *J. Geophys. Res.*, 93, D10, 12,607-12,626, 1988.

Goldman, A., F.J. Murcray, F.H. Murcray, D.G. Murcray, and C.P. Rinsland, "Quantification of Several Atmospheric Gases from

High Resolution Infrared Solar Spectra Obtained at the South Pole in 1980 and 1986," *Mikrochim. Acta (Wien)*, 2, 409-415, 1989.

Goldman, A., F.J. Murcray, D.G. Murcray, J.J. Kosters, C.P. Rinsland, C. Camy-Peyret, J.-M. Flaud, and A. Barbe, "Isotopic Abundance of Stratospheric Ozone from Balloon-Borne Observations of High Resolution Infrared Solar Spectra," *J. Geophys. Res.*, 94, D2, 8467-8473, 1989.

Murcray, F.J., A. Mathews, A. Goldman, P. Johnston and C.P. Rinsland, "NH<sub>3</sub> Column Abundances over Lauder, New Zealand," *J. Geophys. Res.*, 94, 2235-2238, 1989.

Rinsland, C.P., D.W. Johnson, A. Goldman and J.S. Levine, "Evidence for a Decline in the Atmospheric Accumulation Rate of CHClF<sub>2</sub> (CFC-22)," *Nature*, 337, 535-537, 1989.

Goldman, A., F.J. Murcray, R.D. Blatherwick, J.J. Kosters, F.H. Murcray, and D.G. Murcray, "New spectral Features of Stratospheric Trace Gases Identified from High Resolution Infrared Balloon-Borne and Laboratory Spectra," *J. Geophys. Res.*, 94, D12, 14,945-14,955, 1989.

Goldman, A., C.P. Rinsland, R.D. Blatherwick and F.S. Bonomo, "Spectroscopic Line Parameters for the v<sub>6</sub> Band of Carbonyl Fluoride (COF<sub>2</sub>)," *App. Opt.*, 29, 1861-1863, 1990.

Flaud, J.-M., C. Camy-Peyret, C.P. Rinsland, V. Malathy Devi, M.A.H. Smith, and A. Goldman, "Improved Line Parameters for the Ozone Bands in the 10 $\mu$ m Spectral Region," *Appl. Opt.*, 29, 1860-1863, 1990.

Camy-Peyret, C., J.-M Flaud, C.P. Rinsland, M.A.H. Smith, V. Malathy Devi, and A. Goldman, "Line Parameters for Ozone Bands in the 4.8  $\mu$ m Spectral Region," *J. Molec. Spectrosc.*, 139, 353- 360, 1990.

Rinsland, C.P., A. Goldman, F.J. Murcray, R.D. Blatherwick, J.J. Kosters, D.G. Murcray, N. Dak Sze, and S.T. Massie, "Long-Term Trends in the Concentrations of SF<sub>6</sub>, CHClF<sub>2</sub>, and COF<sub>2</sub> in the Lower Stratosphere from Analysis of High-Resolution Infrared Solar Occultation Spectra," *J. Geophys. Res.*, 95, 16,477-16,490, 1990.

Dang-Nhu, M., R. Zander, A. Goldman, and C.P. Rinsland, "Magnetic Dipole Infrared Transitions of the Fundamental Band of Oxygen," *J. Molec. Spectrosc.*, 144, 366-373, 1990.

Rinsland, C.P., M.H. Smith, A. Goldman, and V. Malathy Devi, "Measurements of Lorentz Air-Broadening Coefficients and Relative Intensities in the H<sub>2</sub><sup>16</sup>O Pure Rotational and v<sub>2</sub> Bands

from Long Horizontal Path Atmospheric Spectra," *Appl. Opt.*, 30, 1427-1438, 1991.

Rinsland, C.P., J.S. Levine, R. Zander, A. Goldman, N.D. Sze, M.K.W. Ko, and D.W. Johnson, "Infrared Measurements of HF and HCl Total Columns above Kitt Peak, 1977-1990: Seasonal Cycles and Increases in Total HF, Total HCl, and the HF/HCl Total Column Ratio and Comparisons with Two-Dimensional Model Calculations," *J. Geophys. Res.*, 96, D8, 15,623-15,540, 1991.

Rinsland, C.P., R. Zander, Ph. Demoulin, A. Goldman, M.R. Gunson, C.B. Farmer, F.J. Murcray, and D.G. Murcray, "The Fundamental Quadrupole Band of  $^{14}\text{N}_2$ : Line Positions from High Resolution Solar Absorption Spectra," *J. Molec. Spectrosc.*, 148, 274-279, 1991.

Camy-Peyret, C., J.-M. Flaud, A. Goldman, F.J. Murcray, R.D. Blatherwick, F.S. Bonomo, and D.G. Murcray, "The  $\nu_4$  Band of Carbonyl Fluoride, *J. Molec. Spectrosc.*, 149, 481-490, 1991.

Goldman, A., F.J. Murcray, R.D. Blatherwick, J.J. Kosters, D.G. Murcray, C.P. Rinsland, J.-M. Flaud, and C. Camy-Peyret, "Stratospheric  $\text{HNO}_3$  Measurements from 0.002  $\text{cm}^{-1}$  Resolution Solar Occultation Spectra and Improved Line Parameters in the 5.8- $\mu\text{m}$  Region," *J. Geophys. Res.*, 97, D2, 2561-2567, 1992.

Goldman, A., F.J. Murcray, C.P. Rinsland, R.D. Blatherwick, S.J. David, F.H. Murcray, and D.G. Murcray, "Mt. Pinatubo  $\text{SO}_2$  Column Measurements from Mauna Loa," *Geophys. Res. Lett.*, 19, No. 2, 183-186, 1992.

Goldman, A. and C.P. Rinsland, "HNO<sub>3</sub> line Parameters: New Results and Comparisons of Simulations with High-Resolution Laboratory and Atmospheric Spectra," *JQSRT*, 48, 653-666, 1992.

Rinsland, C.P. and A. Goldman, "Infrared Parameters of  $\text{COF}_2$ ,  $\text{SF}_6$ ,  $\text{ClO}$ ,  $\text{N}_2$  and  $\text{O}_2$ ," *JQSRT*, 48, 693-699, 1992.

Rinsland, C.P., R. Zander, E. Mahieu, P. Demoulin, A. Goldman, D.E. Ehalt, and J. Rudolph, "Ground-Based infrared Measurements of Carbonyl Sulfide Total Column Abundances: Long-Term Trends and Variability," *J. Geophys. Res.*, 97, D5, 5995-6002, 1992.

Rinsland, C.P. and A. Goldman, "Infrared Spectroscopic Measurements of Surface Level Ozone," *Appl. Opt.*, 31, 6969-6971, 1992.

Rothman, L.S., R.R. Gamache, R.H. Tipping, C.P. Rinsland, M.S.H. Smith, D.C. Benner, V. Malathy Devi, J.-M. Flaud, C. Camy-Peyret, A. Perrin, A. Goldman, S.T. Massie, L.R. Brown, and R.A. Toth, "The HITRAN Molecular Database: Editions of 1991 and 1992," *JQSRT*, 48, 469-507, 1992.

Rinsland, C.P. and A. Goldman, "Search for Infrared Absorption Lines of Atmospheric Chlorine Monoxide (ClO)," *J. Quant. Spectrosc. Radiat. Transfer*, 48, 685-692, 1992.

Perrin, A., J.-M. Flaud, C. Camy-Peyret, A. Vasseret, G. Guelachvili, A. Goldman, F.J. Murcray, and R.D. Blatherwick, "The  $v_1$ ,  $2v_2$ , and  $v_3$  Interacting Bands of  $^{14}\text{N}^{16}\text{O}_2$ : Line Positions and Intensities," *J. Molec. Spectrosc.*, 154, 391-406, 1992.

Perrin, A., J.-M. Flaud, C. Camy-Peyret, A. Goldman, F.J. Murcray, R.D. Blatherwick, and C.P. Rinsland, "The  $v_2$  and  $2v_2-v_2$  Bands of  $^{14}\text{N}^{16}\text{O}_2$ : Electron Spin-Rotation and Hyperfine Contact Resonances in the (010) Vibrational State," submitted to *J. Molec. Spectrosc.*, 160, 456-463, 1993.

Rinsland, C.P., M.A.H. Smith, A. Goldman, V. Malathy Devi, and D.C. Benner, "The Fundamental Bands of  $\text{H}^{35}\text{Cl}$  and  $\text{H}^{37}\text{Cl}$ : Line Positions from High Resolution Laboratory Data," *J. Molec. Spectrosc.*, 159, 274-278, 1993.

Ko, M.K.W., N. Dak Sze W.C. Wang, G. Shia, A. Goldman, F.J. Murcray, and C.P. Rinsland, "Atmospheric Sulfur Hexa Fluoride: Sources, Sinks, and Greenhouse Warming," *J. Geophys. Res.*, 98, 10,499-10,507, 1993.

Camy-Peyret, C., J.-M. Flaud, A. Perrin, C.P. Rinsland, and A. Goldman, "Stratospheric  $\text{N}_2\text{O}_5$ ,  $\text{CH}_4$  and  $\text{N}_2\text{O}$  Profiles from IR Solar Occultation Spectra," *J. Atm. Chem.*, 16, 31-40, 1993.

Perrin, A., J.-M. Flaud, C. Camy-Peyret, A. Goldman, F.J. Murcray, R.D. Blatherwick, and C.P. Rinsland, "The  $v_2$  and  $2v_2-v_2$  Bands of  $^{14}\text{N}^{16}\text{O}_2$ : Electron Spin-Rotation and Hyperfine Contact Resonances in the (010) Vibrational State," submitted to *J. Molec. Spectrosc.*, 160, 456-463, 1993.

Rinsland, C.P., M.A.H. Smith, A. Goldman, V. Malathy Devi, and D.C. Benner, "The Fundamental Bands of  $\text{H}^{35}\text{Cl}$  and  $\text{H}^{37}\text{Cl}$ : Line Positions from High Resolution Laboratory Data," *J. Molec. Spectrosc.*, 159, 274-278, 1993.

Ko, M.K.W., N. Dak Sze W.C. Wang, G. Shia, A. Goldman, F.J. Murcray, and C.P. Rinsland, "Atmospheric Sulfur Hexa Fluoride: Sources, Sinks, and Greenhouse Warming," *J. Geophys. Res.*, 98, 10,499-10,507, 1993.

Camy-Peyret, C., J.-M. Flaud, A. Perrin, C.P. Rinsland, and A. Goldman, "Stratospheric  $\text{N}_2\text{O}_5$ ,  $\text{CH}_4$  and  $\text{N}_2\text{O}$  Profiles from IR Solar Occultation Spectra," *J. Atm. Chem.*, 16, 31-40, 1993.

Rinsland, C.P., M.R. Gunson, M.C. Abrams, L.L. Lowes, R. Zander, E. Mahieu, A. Goldman, M.K.W. Ko, J.M. Rodriguez, and N.D. Sze, "Heterogeneous Conversion of  $\text{N}_2\text{O}_5$  to  $\text{HNO}_3$  in the Post -

Mt. Pinatubo Eruption Stratosphere," J. Geophys. Res., 99, 8213-8219, 1994.

Goldman, A., C.P. Rinsland, F.J. Murcray, R.D. Blatherwick, and D.G. Murcray, "High Resolution Studies of Heavy NO<sub>y</sub> Molecules in Atmospheric Spectra," JQSRT, 52, 367-377, 1994.

Perrin, A., J.-M. Flaud, C. Camy-Peyret, A. Goldman, C.P. Rinsland, and M.R. Gunson, "Identification of the HNO<sub>3</sub> 3v<sub>9</sub>-v<sub>9</sub> Band Q Branch in Stratospheric Solar Occultation Spectra," JQSRT, 52, 319-322, 1994.

Rinsland, A. Goldman, F.J. Murcray, S.J. David, R.D. Blatherwick, and D.G. Murcray, "Infrared Spectroscopic Measurements of the Ethane (C<sub>2</sub>H<sub>6</sub>) Total Column above Mauna Loa, Hawaii: Seasonal variations," JQSRT, 52, 273-279, 1994.

Goldman, A., J.R. Gillis, C.P. Rinsland, and J.B. Burkholder, "Improved Line Parameters for the X<sup>2</sup>Π - X<sup>2</sup>Π (1-0) Bands of <sup>35</sup>ClO and <sup>37</sup>ClO," JQSRT, 52, 357-359, 1994.

David, S.J., F.J. Murcray, A. Goldman, C.P. Rinsland, and D.G. Murcray, "The Effect of the Mt. Pinatubo Aerosol on the HNO<sub>3</sub> Column over Mauna Loa, Hawaii," GRL, 21, 1003-1006, 1994.

Rinsland, C.P., M.R. Gunson, M.C. Abrams, R. Zander, E. Mahieu, A. Goldman, M.K.W. Ko, J.M. Rodriguez, and N.D. Sze, "Profiles of Stratospheric Chlorine Nitrate (ClONO<sub>2</sub>) from ATMOS/ATLAS 1 Infrared Solar Occultation Spectra," JGR, 99, 18,894-18,900, 1994.

Perrin, A., J.-M. Flaud, C. Camy-Peyret, B.P. Winnewisser, A. Goldman, F. J. Murcray, R.D. Blatherwick, F.S. Bonomo, D.G. Murcray, and C.P. Rinsland, "First Analysis of the 3v<sub>9</sub>-v<sub>9</sub>, 3v<sub>9</sub>-v<sub>5</sub> and 3v<sub>9</sub>-2v<sub>9</sub> Bands of HNO<sub>3</sub>: Torsional Splitting in the v<sub>9</sub> Vibrational Mode," J. Molec. Spectrosc., 166, 224-243, 1994.

Goldman, A. C.P. Rinsland, B. Canova, R. Zander, and M. Dang-Nhu, "Improved Spectral Parameters for the <sup>16</sup>O<sub>2</sub> Infrared Forbidden Lines in the X<sup>3</sup>Σ<sub>g</sub><sup>-</sup> (0-1) Band," JQSRT, 54, 757-765, 1995.

Rinsland, C.P., M.R. Gunson, M.K. Ko, D.W. Weisenstein, R. Zander, M.C. Abrams, A. Goldman, N.D. Sze, and G.K. Yue, "A Source of Sulphur Dioxide in the Upper Stratosphere," Geophys. Res. Lett., 22, 1109-1112, 1995.

Sherlock, V.J., N.B. Jones, W.A. Matthews, F.J. Murcray, R.D. Blatherwick, D.G. Murcray, A. Goldman, C.P. Rinsland, and D.W.T. Griffith, "Increases in the Vertical Column Abundance of HCFC-22 (CHClF<sub>2</sub>) above Lauder, New Zealand, between 1985 and 1994," J. Geophys. Res., in press, 1997.

Rinsland, C.P., B.J. Connor, N.B. Jones, I. Boyd, W.A. Matthews, A. Goldman, F.J. Murcray, D.G. Murcray, and S.J. David, "Comparison of Infrared and Dobson Total Ozone Columns Measured from Lauder, New Zealand," *Geophys. Res. Lett.*, 23, 1025-1028, 1996.

Brown, L.R., M.R. Gunson, R.A. Toth, F.W. Irion, C.P. Rinsland, and A. Goldman, "The 1995 Atmospheric Trace Molecule Spectroscopy (ATMOS) Linelist," *Appl. Opt.*, FTS Special Issue, 35, 2828-2848, 1996.

Abrams, M.C., M.R. Gunson, A. Goldman, C.P. Rinsland, and R. Zander, "Observations of the Infrared Solar Spectrum from Space by the ATMOS Experiment," *Appl. Opt.*, FTS Special Issue, 35, 2747-2751, 1996.

Rinsland, C.P., E. Mahieu, R. Zander, M.R. Gunson, R.J. Salawitch, A.Y. Chang, A. Goldman, M.C. Abrams, M.M. Abrams, M.J. Newchurch, and F.W. Irion, "Trends of OCS, HCN, SF<sub>6</sub>, CHClF<sub>2</sub>, (HCFC-22) in the Lower Stratosphere from 1985 and 1994 Atmospheric Trace Molecule Spectroscopy Experiment Measurements Near 30°N Latitude," *Geophys. Res. Lett.*, 23, 2349-2352, 1996.

Sherlock, V.J., N.B. Jones, W.A. Matthews, F.J. Murcray, R.D. Blatherwick, D.G. Murcray, A. Goldman, C.P. Rinsland, and D.W.T. Griffith, "Increases in the Vertical Column Abundance of HCFC-22 (CHClF<sub>2</sub>) above Lauder, New Zealand, between 1985 and 1994," *J. Geophys. Res.*, 102, 8861-8865, 1997.

Goldman, A., W.G. Schoenfeld, T.M. Stephen, F.J. Murcray, C.P. Rinsland, A. Barbe, A. Hamdouni, J.-M. Flaud, and C. Camy-Peyret, "Isotopic Ozone in the 5μ Region from High Resolution Balloon-Borne and Ground-Based FTIR Solar Spectra," *JQSRT*, 59, 231-244, 1998.

Goldman, A., C.P. Rinsland, A. Perrin, and J.-M. Flaud, "HNO<sub>3</sub> Line Parameters: 1996 HITRAN Update and New Results," *JQSRT*, 60, 851-861, 1998.

Goldman, A., C.P. Rinsland, J.-M. Flaud, and J. Orphal, "ClONO<sub>2</sub> Spectroscopic Line Parameters and Cross-Sections in HITRAN 1996," *JQSRT*, 60, 875-882, 1998.

Goldman, A., L.R. Brown, M.N. Spencer, C. Chackerian, Jr., L.P. Giver, C.P. Rinsland, L.H. Coudert, V. Dana, and J.-Y. Mandin, "NO Line Parameters: Review of 1996 HITRAN Update and New Results," *JQSRT*, 60, 825-838, 1998.

Rinsland, C.P., J.-M. Flaud, A. Goldman, A. Perrin, C. Camy-Peyret, M.A.H. Smith, V. Malathy Devi, D.C. Benner, A. Barbe, T.M. Stephen, and F.J. Murcray, "Spectroscopic Parameters for Ozone

and its Isotopes: Current Status, Prospects for Improvement, and the Identification of  $^{16}\text{O}^{16}\text{O}^{17}\text{O}$  and  $^{16}\text{O}^{17}\text{O}^{16}\text{O}$  Lines in Infrared Ground-Based and Stratospheric Solar Absorption Spectra," JQSRT, 60, 803-814, 1998.

Rinsland, C.P., M.R. Gunson, P. Wang, R.F. Arduini, B.A. Baum, P. Minnis, A. Goldman, M.C. Abrams, R. Zander, E. Mahieu, R.J. Salawitch, H.A. Michelsen, F.W. Irion, and M.J. Newchurch, "ATMOS/ATLAS 3 Infrared Profile Measurements of Clouds in the Tropical Upper Troposphere," JQSRT, 60, 903-919, 1998.

Rinsland, C.P., M.R. Gunson, P. Wang, R.F. Arduini, B.A. Baum, P. Minnis, A. Goldman, M.C. Abrams, R. Zander, E. Mahieu, R.J. Salawitch, H.A. Michelsen, F.W. Irion, and M.J. Newchurch, "ATMOS/ATLAS 3 Infrared Profile Measurements of Trace Gases in the November 1994 Tropical and Subtropical Upper Troposphere," JQSRT, 60, 891-901, 1998.

Perrin, A., J.-M. Flaud, A. Goldman, C. Camy-Peyret, W.J. Lafferty, Ph. Arcas, and C.P. Rinsland, "NO<sub>2</sub> and SO<sub>2</sub> line parameters: 1996 HITRAN Update and New Results," JQSRT, 60, 839-850, 1998.

Coffey, M.T., A. Goldman, J.W. Hannigan, W.G. Mankin, W.G. Schoenfeld, C.P. Rinsland, C. Bernardo, and D.W.T. Griffith, "Improved Vibration-Rotation (0-1) HBr Line Parameters for Validating High Resolution Infrared Atmospheric Spectra Measurements," JQSRT, 60, 863-867, 1998.

Rothman, L.S., C.P. Rinsland, A. Goldman, S.T. Massie, J.-M. Flaud, A. Perrin, V. Dana, J.-Y. Mandin, J. Schroeder, A. McCann, R.R. Gamache, R.B. Watson, K. Yoshino, K. Chance, K. Jucks, L.R. Brown, V. Nemtchinov, and P. Varanasi, "The HITRAN Molecular Spectroscopic Database and HAWKS (HITRAN Atmospheric Workstation)," JQSRT, 60, 665-710, 1998.

Goldman, A., K.V. Chance, M.T. Coffey, W.G. Mankin, and C.P. Rinsland, "Improved Line Parameters for the X<sup>1</sup> $\Sigma^+$  (0-0) and (0-1) Bands of HI," JQSRT, 60, 869-874, 1998.

Rinsland, C.P., N.B. Jones, B.J. Connor, J.A. Logan, N.S. Pougatchev, A. Goldman, F.J. Murcay, T.M. Stephen, A.S. Pine, R. Zander, P. Demoulin, and E. Mahieu, "Northern and Southern Hemisphere Ground-Based Infrared Spectroscopic Measurements of Tropospheric Carbon Monoxide and Ethane," J. Geophys. Res., 103, 28,197-28,217, 1998.

Rinsland, C.P., R.J. Salawitch, G.L. Manney, M.R. Gunson, H.A. Michelsen, S. Solomon, R. Zander, E. Mahieu, A. Goldman, M.J. Newchurch, and F.W. Irion, "Polar Stratospheric Descent of NO<sub>2</sub> and CO and Arctic Denitrification during Winter 1992-1993," J. Geophys. Res., 104, 1847-1861, 1999.

Perrin, A., J.-M. Flaud, F. Keller, A. Goldman, R.D. Blatherwick, F.J. Murcray, and C.P. Rinsland, "New Analysis of the  $v_8 + v_9$  Band of  $\text{HNO}_3$  Line Positions and Intensities," *J. Molec. Spectrosc.*, 194, 113-123, 1999.

Rinsland, C.P., A. Goldman, F.J. Murcray, T.M. Stephen, N.S. Pougatchev, J. Fishman, S.J. David, R.D. Blatherwick, P.C. Novelli, N.B. Jones, and B.J. Connor, "Infrared Solar Spectroscopic Measurements of Free Tropospheric CO,  $\text{C}_2\text{H}_6$ , and HCN above Mauna Loa, Hawaii: Seasonal Variations and Evidence for Enhanced Emissions from the Southeast Asian Tropical Fires of 1997-1998," *J. Geophys. Res.*, 104, 18,667-18,680, 1999.

Perrin, A., C.P. Rinsland, and A. Goldman, "Spectral Parameters for the  $v_6$  Region of  $\text{HCOOH}$  and its Measurement in the Tropospheric Spectrum," *J. Geophys. Res.*, 104, 18,661-18,666, 1999.

Goldman, A., R.R. Gamache, A. Perrin, J.-M. Flaud, C.P. Rinsland, and L.S. Rothman, "HITRAN Partition Functions and Weighted Transition-Moments Squared," *JQSRT*, in press, 1999.

Goldman, A., M.T. Coffey, T.M. Stephen, C.P. Rinsland, W.G. Mankin, "Isotopic OCS in the Troposphere and Lower Stratosphere Determined from High Resolution Infrared Solar Absorption Spectra," submitted to *JQSRT*, 1999.

Rinsland, C.P., A. Goldman, B.J. Connor, T.M. Stephen, N.B. Jones, S.W. Wood, F.J. Murcray, S.J. David, R.S. Blatherwick, N.S. Pougatchev, R. Zander, E. Mahieu, and P. Swmoulin, "Correlation Relationships of Stratospheric Molecular Columns from High Spectral Resolution, Ground-Based Infrared Solar Absorption Spectra," submitted to *J. Geophys. Res.*, 1999.

Stephen, T.M., A. Goldman, A. Perrin, J.-M. Flaud, F. Keller, and C.P. Rinsland, "New high resolution analysis of the  $3v_3$  and  $2v_1 + v_3$  bands of nitrogen dioxide ( $\text{NO}_2$ ) by Fourier transform spectroscopy," submitted to *J. Molec. Spectrosc.*, 1999.

Gillis, J.R., A. Goldman, and C.P. Rinsland, "Line parameters for the  $\text{A}^2\Sigma - \text{X}^2\Pi$  bands of OH," to be submitted to *JQSRT*, 1999.





UNIVERSITY OF  
**DENVER**

Department of Physics & Astronomy  
2112 E. Wesley Ave.  
Denver, CO 80208  
303.871.2238  
Fax 303.871.4405  
<http://www.du.edu/physastron>

Nov. 15, 1999

**NASA Center for Aerospace Information(CASI)**  
**Parkway Center**  
**7121 Standard Dr.**  
**Hanover, MD 21076-1320**

Dear Sir,

Enclosed is one copy(one-sided, not stapled) of the Final Report  
for D.U.-NASA Langley Collaborative Study NCCI-48.

A copy was also sent to the grants officer(Mr. R.T. Lacks) and to  
the technical officer(Dr. C.P. Rinsland).

NASA's continuing support and encouragement are greatly  
appreciated.

Sincerely Yours,

*Aaron Goldman*  
Dr. Aaron Goldman  
Senior Research Physicist  
Professor of Physics